Landscape Ecology

Original research

How does a transforming landscape influence bird breeding success?

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Abstract

Context

The conversion of agricultural landscapes to tree plantations is a major form of landscape transformation worldwide, but its effects on biodiversity, particularly key population processes like reproductive success, are poorly understood.

Objectives

We compared bird breeding success between woodland remnants surrounded by maturing stands of plantation Radiata Pine and a matched set of woodland remnants in semi-cleared grazing land.

Methods

Our study was conducted in the Nanangroe region in south-eastern New South Wales, Australia. Using repeated field measurements, we quantified bird breeding success in 23 woodland remnants; 13 surrounded by Radiata Pine plantations and 10 on farms where remnants were surrounded by semi-cleared grazing land. We matched the attributes of native remnant patches between two types of matrix.

Results

We found that: (1) rates of nesting success of smaller-bodied birds in woodland remnants surrounded by grazing land were significantly higher than in woodland remnants surrounded by pine plantations; and (2) taxa with domed nests were more successful at nesting than species that constructed open cup/bowl nests in woodland remnants within farmlands.

Conclusions

Our findings suggest that bird breeding success in remnant woodland patches is significantly diminished as a result of the conversion of semi-cleared grazing land to pine plantations.

Keywords: Agricultural landscape, breeding success, landscape change, matrix ecology, native vegetation cover, pine plantations.

Introduction

Landscape conversion is a major driver of species decline and local extinction (Bobo et al 2006; Davidai et al 2015; Dornelas et al 2014). The conversion of agricultural landscapes to tree plantations is a significant form of landscape transformation worldwide, and is part of meeting increasing demands for wood and paper products, as well as timber and carbon sequestration (FAO 2010; Hulvey et al 2013; Mortelliti and Lindenmayer 2015; Paquette and Messier 2010). Planted forests are predicted to cover 300 million hectares globally by 2020 (FAO 2010; Lindenmayer et al 2015b).

There is a wealth of literature on the response of biodiversity to agricultural landscape conversion to tree plantations (Felton et al 2010; Lindenmayer and Fischer 2006), particularly bird biota (Lindenmayer et al 2015a; Mortelliti and Lindenmayer 2015; Wilson et al 2014). The vast majority of these studies have documented patterns of species distribution and abundance but the key ecological processes underpinning these patterns remain largely unstudied. Breeding success is a critical ecological process influencing the likely persistence of species in natural and human-modified landscapes (Cruz-McDonnell and Wolf 2016; Gill 1985; With et al 2006). Yet, there have been remarkably few studies of bird breeding success in transforming landscapes (although see Zanette et al 2000). This, in turn, limits understanding of the factors governing species occurrence and patch occupancy in such landscapes.

Areas converted to tree plantations are often in fragmented landscapes that contain remnant patches of native vegetation (Driscoll et al 2013; Lindenmayer 2009). Some species occupying native vegetation patches may be susceptible to edge effects as well as changes in the surrounding matrix (Driscoll et al 2013) including impaired breeding performance (Hinsley et al 1999; Zanette et al 2000). For example, nest predation rates may differ in small patches due to increased edge effects (Lahti 2001; Newmark and Stanley 2011) as well as potential differences in landscape context (Lloyd et al 2005) such as the predator community occupying the matrix (DeGregorio et al 2014; Donovan et al 1997). Rates of nest parasitism are also influenced by both edge effects and landscape context (Howell et al 2007; Lloyd et al 2005). However, there have been few studies of matrix effects on breeding success of birds inhabiting plantation-dominated landscapes.

To close this knowledge gap, we conducted an empirical study of bird breeding success in patches of remnant native woodland surrounded by areas which, in the last two decades, have been undergoing transformation from semi-cleared grazing land to plantations of exotic Radiata Pine (*Pinus radiata*). We compared bird breeding success within woodland patches surrounded by maturing pine stands with a replicated set of woodland patches where the surrounding landscape was dominated by semi-cleared grazing farmlands. Specifically, we posed the following three key questions:

Q1: Are there differences in rates of breeding success between woodland remnants surrounded by pine plantations and woodland patches located in semi-cleared grazing paddocks? We postulated that bird breeding success would be higher in remnants surrounded by plantations than in remnants within farmlands. This prediction was based on likely differences in predator abundance and microclimatic conditions that would influence nesting success. First, bird data previously collected in our study area showed that the number of species of avian predators within farmlands was significantly higher than in plantations (χ_1^2 = 14.421 and P = 0.001 for 2009, χ_1^2 = 15.109 and P = 0.001 for 2011). Second, remnants surrounded by pine plantations would be characterized by more stable micro-environmental conditions than remnants in semi-cleared grazing environments. Such conditions include reduced wind speeds and less variation in temperature. Reproductive performance in birds may be promoted under such conditions (see DuRant et al 2013; Hepp and Kennamer 2012). In addition, the two kinds of woodland patches in our study differed markedly in landscape context (*sensu* Lindenmayer and Fischer 2006) and this will produce differences in edge contrast and edge effects, patterns of habitat connectivity, and other factors (Harper et al. 2005). Fragmentation theory and landscape ecology (matrix) theory suggest that differences in landscape context should have marked effects on biota, including reproductive success (see Driscoll et al 2013).

Q2: Is there a relationship between bird breeding success and the amount of woody vegetation cover in the landscape surrounding nests? We postulated that nests in areas surrounded by large amounts of native woody vegetation cover would be more successful than nests where the amount of surrounding native woody cover was limited. We based this prediction on previous work showing that larger areas of native eucalypt woodland provide a greater variety of food resources for birds than small areas of woodland (Zanette et al 2000).

Q3: Is there a relationship between bird breeding success and life-history attributes or nest characteristics and do these relationships vary between woodland patches in farmlands and plantations? Previous work has revealed that bird breeding success may be linked with life-history attributes such as nest type and nest height (Best and Stauffer 1980; Collias 1997; Colombelli-Négrel and Kleindorfer 2009; Noske et al 2008) although these relationships may vary between different ecosystems (e.g. Knutson et al 2004; Massaro et al 2013). We predicted that relationships between life history attributes and bird breeding success would be prominent as an earlier experiment in a neighbouring region found depressed levels of occurrence among open cup nesters in forest patches surrounded by recently harvested pines versus uncut pine stands (Lindenmayer et al 2009).

Breeding success is a critical population process influencing the persistence of bird species in natural and human-dominated landscapes (Cruz-McDonnell and Wolf 2016; Gill 1985; With et al 2006). Therefore, our results will help inform effective strategies that attempt to integrate biodiversity conservation and wood production in plantation-dominated landscapes. This is particularly important as tree plantations occupy a large and rapidly increasing area worldwide (Lindenmayer et al 2015b).

Methods

Study area

Our study area covers approximately 56 square kilometres in the Nanangroe region, 20 km south-east of Jugiong in south-eastern New South Wales, Australia (34˚55´-35˚0´S, 148˚25´-148˚35´E) (Figure 1). The Nanangroe region has a temperate climate with an annual rainfall of 900 to 1200 mm (Bureau of Meteorology 2015). The native vegetation cover in our study area is dominated by White Box (*Eucalyptus albens*), Yellow Box (*E. melliodora*), Red stringybark (*E. macrorhyncha*), Red Box (*E. polyanthemos*), and Blakely's Red Gum (*E. blakelyi*). Approximately 80% of the original native vegetation in the region has been cleared for grazing and cropping since European settlement (Lindenmayer et al 2008). The region has been undergoing extensive landscape transformation from semi-cleared grazing land to Radiata Pine plantations since the late 1990s. A major series of studies of the response of biodiversity to this landscape transformation has been taking place at 131 long-term monitoring sites first established in 1998 (Lindenmayer et al 2015a; Lindenmayer et al 2008; Lindenmayer et al 2001; Mortelliti et al 2015a; Mortelliti and Lindenmayer 2015; Mortelliti et al 2015b; Mortelliti et al 2014). The investigation reported here is the first to quantify patterns of bird breeding success at Nanangroe.

#Figure 1 approximately here#

Study sites

For the study reported here on bird breeding success, we selected a subset of 23 woodland remnant sites from the 131 permanently-marked long-term monitoring sites at Nanangroe (for more details on the experimental design see Lindenmayer et al 2008; Lindenmayer et al 2001). The 23 sites comprised 13 woodland remnant sites surrounded by Radiata Pine plantations and 10 sites on farms where remnants were surrounded by semi-cleared grazing land.

We selected our sites to generally match the conditions of native remnant patches between two types of matrix. The average size of woodland remnants within farmlands and pine plantations was 5.2 hectares and 4.7 hectares, respectively (χ_1^2 = 0.026, P = 0.873). As riparian areas often support more biodiversity than elsewhere in a landscape (Jenkins et al 2013), we considered they may be superior breeding habitats (i.e. invertebrates as food and plants as habitats and food). Therefore, we selected the same number of riparian sites from each of the two types of matrix (n=3 in either type of matrix).

Vegetation cover in the majority of sites was intact and in a relatively good condition, with a midstorey of *Acacia* spp, *Kunzea* spp and *Eucalyptus* saplings. The understorey was dominated by the exotic Blackberry (*Rubus fruticosus*). Other habitat structures, such as hollow-bearing trees and fallen logs, also were present at all of our sites. There was an intermediate level of livestock grazing in all woodland remnants (i.e. sites in both the plantations and the farmlands).

Surveys for bird breeding success

The breeding season for the majority of bird species in our study region is August to February (Beruldsen 2003). To maximise the chance of detecting breeding events, we searched for nests during the peak breeding season. Accordingly, we conducted surveys between September and December in 2012 and between October and December in 2013. Not all sites could be surveyed each year. In the farmland matrix, seven sites were surveyed in 2012 and ten in 2013. Corresponding figures for the pine matrix are eight and twelve sites.

We located nests by following birds with nesting materials or searching likely places for breeding such as clumps of mistletoe and in tree hollows. For each nest, we recorded the GPS coordinates of the nest, bird species, and the species of plant on which a nest was built. We also measured nest height from ground level.

Every site was visited at least eight times to search for new nests during each survey season. We re-visited the sites every five to 14 days, with more frequent visits towards the end of survey seasons to determine the fate of nestlings. At every visit, we recorded nesting stage (building nest/incubating/nestlings/fledglings) until breeding success was determined. We defined the construction of nests as a 'Nesting Attempt' and the observation of at least one fledgling as 'Nesting Success'. We did not include nests in the analyses reported here for which we could not determine success.

We limited our nest searching efforts to an area within approximately 50 meters either side of a permanently marked 200 meter transect on each of the 23 sites in our study. However, we also recorded and monitored nests incidentally found outside of this searching area. Every time we visited each site, we spent approximately two hours searching for new nests and a further 20 minutes of observation time to document the status (e.g., active vs inactive) of each nest.

We recorded all nests detected in our repeated surveys. However, for subsequent data analyses we excluded nests constructed by water birds (most of which have a fundamentally different nesting niche relative to other bird species) and those of the migratory White-browed Woodswallow (*Artamus superciliosus*). The White-browed Woodswallow is an irruptive, occasional migrant to our study area, and the large numbers that arrived to nest in 2013 would have skewed the results.

Definition of small versus large-bodied birds

To calculate a median body size of birds occurring in the study region, we used data from previous field surveys over the past 16 years for all of the species in the Nanangroe region (Lindenmayer et al 2008; Lindenmayer et al 2001). We excluded water birds since they have very different breeding ecology relative to the remainder of the bird assemblage. Median body mass of all bird species in the study area was 48.25 grams, and we used this value to distinguish between small-bodied birds and large-bodied birds. For instance, we classified the Brown Treecreeper (*Climacteris picumnus*) and Rufous Songlark (*Cincloramphus mathewsi*) as small-bodied birds and the Magpie-lark (*Grallina cyanoleuca*) and Noisy Friarbird (*Philemon corniculatus*) as large-bodied birds (Appendix 1).

Woody Vegetation Cover

We used fine-scale satellite data on vegetation cover to calculate the amount of native woody vegetation cover (including scattered paddock trees) in radii of 50 m, 100 m, 200 m, 300 m and 500 m surrounding each nest. Our source data were the time series grids of Forest Extent and Change (version 9), produced by the Australian Government Department of Environment (National Carbon Accounting System, http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/ncas/reports/tech09.html). We used Landsat satellite imagery to discriminate between forest and non-forest cover at a grid resolution of 25m.

Statistical Analyses

We compared the number of nests per site x year combination in remnants surrounded by pine plantations with those within farmlands by fitting a generalised linear model (GLM) with a quasi-Poisson response and a logarithmic link function. In a similar way, we compared the effect of the surrounding matrix on quantities such as success rate by assuming that the number observed had a quasi-binomial distribution. For these models, we used approximate F-tests to assess significance. To assess the effect of variables measured for individual nests, body mass of bird, nest height, and nest type, we used logistic regression with a logit link function and assumed a Bernoulli distribution for the data. The response variable was breeding success (0 = Failed, 1= Success). We used Wald statistics to quantify the significance of the potential predictors.

As part of preliminary analyses, we tested for the effects of phylogeny on differences in the bird breeding success among the two different kinds of remnants but found no evidence for such effects. We suggest that this result may have been in part because of the large range of bird families (N =23) that occurred in both kinds of remnants. We also tested for the effects of spatial dependence in nesting success; successful nests may have been more likely to have been near to other successful nests, but again found no evidence for such effects. Finally, we tested for differences in the number of nests and nesting success between riparian and non-riparian areas and found no evidence for any significant differences between such kinds of sites. We used GenStat 64-bit Release 18.1 to conduct all statistical analyses.

Results

We found a total of 175 nests (42 species) over the two breeding seasons. Of these, five nests were constructed by water birds (Appendix 1) and 12 were constructed by the White-browed Woodswallow were excluded from our study leaving 158 nests for subsequent data analyses. Of these 114 were in remnants surrounded by farmland (70 were small bodied bird species, 44 were large bodied species) and 44 were in remnants surrounded by plantation (24 were small bodied, 20 were large bodied).

Relationships between breeding success and matrix types

We detected an average of approximately three times more nests per site in remnants within farmlands than remnants surrounded by plantations ($F_{1,35}$ = 19.7, P <0.001; Table 1). The proportion of generalist (non-woodland dependent) avian predator nests in remnants surrounded by pine plantations was significantly higher (31.8%) than that of remnants within farms (7.0%) ($F_{1,35}$ = 11.8, P = 0.002).

Of the 158 nests selected for analyses of breeding success, 97 nests (27 species) successfully produced at least one fledgling. Overall, we found no difference in the rate of nest success between remnants within farmlands (63.2%) and remnants surrounded by plantations (56.8%) ($F_{1,35}$-0.39, P = 0.54).

Relationships between breeding success and vegetation cover

We found no relationships between nest success and the amount of native woody vegetation cover in the surrounding landscape (P > 0.05 for any radii).

Relationships between breeding success and bird life-history characteristics

<u>Nest type</u>

We found a significant relationship between nesting success and nest type (χ_1^2 = 6.113, P = 0.013) for remnants surrounded by farmland. The predicted breeding success of open cup/bowl nesters was 54.8% and that of domed nesters was 84%. By contrast, there was no difference in breeding success between two nest types in remnants surrounded by pine plantations (predicted success rate of cup/bowl nests = 0.333 ± 0.192, dome nests = 0.353 ± 0.116).

<u>Body size</u>

Larger species bred significantly more successfully than smaller species, irrespective of remnant type (χ_1^2 = 11.3, *P* <0.001; Figure 2). For our study, examples of bird species with 7g of average body mass included the Brown Thornbill (*Acanthiza pusilla*) and the White-throated Gerygone (*Gerygone olivacea*). Example species with larger body mass were the Noisy Friarbird (*Philemon corniculatus*, 100g body weight) and the Australian Raven (*Corvus coronoides*; 600g body weight).

#Figure 2 approximately here#

Nest height

We found no significant relationships between breeding success and nest height when all birds were considered (χ_1^2 = 2.1, P 0.142). We also failed to find a significant relationship with either remnant type (X^2 = 3.511, P = 0.061). However, birds smaller than the median body mass bred significantly more successfully at a lower nest height (χ_1^2 = 7.8, P = 0.005), whereas the success rate of species with larger body mass than the median weight was significantly greater at a higher locations ((χ_1^2 = 4.477, P = 0.034). Predicted breeding success rates for smaller species were 64.7% and 43.4% for one metre and five metres of nest height, respectively.

Discussion

The area of tree plantations is expanding globally at a rate of 5 million hectares annually (FAO 2010; Guida-Johnson and Zuleta 2013; Watson et al 2014). Such kinds of landscape conversion can have significant impacts on biodiversity (Felton et al 2010) and can influence the abundance and occurrence of bird species in remaining native vegetation patches (Mortelliti et al 2014; Waltert et al 2004). Quantifying how bird breeding success changes in transforming plantation landscapes is a critical part of understanding the ecological processes affecting patterns of species abundance and distribution in these human-modified environments.

We found nest success rates of species smaller than the median body size in the Nanangroe region were significantly greater in remnants surrounded by farmlands than in remnants surrounded by stands of Radiata Pine plantation. There also were relationships between bird life-history characteristics and nest success, especially nest type. We discuss our key findings in the remainder of the paper and conclude with a summary of the conservation implications of this work.

Breeding success and matrix type

At the outset of our study we predicted that breeding success in woodland remnants surrounded by stands of Radiata Pine plantation would be higher than woodland remnants within farmlands. However, we found strong evidence for the opposite effect for birds for which average body mass was smaller than a median size in the region. We also detected significantly more nests in remnants within farmlands than in remnants surrounded by stands of Radiata Pine plantation. Several factors may explain these results. First, densely spaced plantation trees may help conceal nests for some species thereby reducing the number of nests in adjacent woodlands remnants which are surrounded by stands of plantation Radiata Pine. Second, there may be differences in food availability between woodland remnants within the different matrices (Driscoll et al 2013). Invertebrates are a key prey item for many birds in our study area, particularly for smaller-bodied birds. Sweaney et al (2015) found fewer ground-active beetles and a reduced overall beetle diversity in remnants surrounded by plantations than remnants within farmlands. Reduced availability of food may result in nests/nestlings being left unattended for long periods, leaving them susceptible to predation and/or starvation (Rastogi et al 2006).

Differences in the abundance of avian predator nests may be a third factor explaining contrasts in breeding success between remnants within farmlands and remnants surrounded by stands of Radiata Pine plantation is. Our long-term field survey data from the Nanangroe region indicated that avian predators were more abundant on farms than plantations in both 2012 (χ_1^2 = 10.582, P = 0.0019) and 2013 (χ_1^2 = 12.709, P = 0.001). However, surprisingly, we found significantly more nests of avian predators, particularly ravens, in remnants surrounded by pine plantations than in woodland remnants on farms (Appendix 1). This suggests that the abundance of predators may not be directly related to the abundance of nests for some species of avian predators. The presence of nesting avian predators also may have discouraged other bird species from breeding.

Land surrounding woodland remnants (the matrix) could provide food resources and/or habitat for some bird species (Manning et al 2004). Some species may have perceived pine trees at the edges of woodland remnants as being relatively safe nesting sites (Chalfoun and Martin 2010; Dukas 2013), particularly small-bodied species such as the Grey Fantail (*Rhipidura albiscapa*) and various species of Thornbills (*Acanthiza* spp) (Appendix 2).

Relationships between breeding success and vegetation cover

At the outset of this study we predicted that nest success would be greater at those nests characterized by large areas of surrounding native woody vegetation cover as found in other environments around the world, including those in Europe (Mackenzie et al. 2014). However, we found no evidence of such effects and the reasons for the paucity of such effects remain unclear. The discrepancy between the results of this study and those of other investigations suggests that the effects of the amount of surrounding vegetation cover on bird breeding success is an area for further study, potentially involving greater field effort and more sites that we were able to examine.

Relationships between breeding success and bird life history attributes

We found that for woodland remnants on farms, birds with domed nests bred significantly more successfully than species with open cup/bowl nests. However, there were no relationships between nest type and breeding success in remnants surrounded by pine plantations. This suggests that different mechanisms may be driving nest success in woodland remnants with different surrounding matrices. Our results may be attributed to several factors. In remnant on farms, differences in nest success may be driven by climate and/or predation pressures. First, birds with domed nests may have been better able to survive the extreme temperatures which characterized the 2013 field season (Appendix 3) (Collias 1997).

Conversely, some species of open cup/bowl nesters, such as the Willie Wagtail (*Rhipidura leucophrys*) and Flycatchers (*Myiagra* spp), nested in exposed places, such as on dead branches, where visually-cued avian predators could detect them (Gardner 1998). In remnants surrounded by pine plantations, limited availability of food (Sweaney et al 2015) may underpin the absence of relationships between nest type and breeding success. We acknowledge that the relatively small sample sizes in our study also may have led to a paucity of relationships between nest type and breeding success, although extensive field searching coupled with the considerable difficulty in finding and then repeatedly monitoring nests in our study precluded the inclusion of more nests.

We found that larger species of birds bred significantly more successfully than smaller birds. Larger species may be able to better defend their nests than smaller species (Remeš et al 2012). Ford (1999) found the Noisy Friarbird aggressively and successfully protected their conspicuous nests from avian predators. In our study, the Noisy Friarbird accounted for a large percentage of nests of larger species. Indeed, this species was characterised by a very high breeding success rate (71.4%).

We found no significant relationships between breeding success and nest height either overall or within either of the types of woodland patches. However, the breeding success of smaller-bodied birds was negatively correlated with nest height and the opposite effect was identified for larger-bodied birds. In our study sites, the understorey was often comprised of thickets of the exotic Blackberry (*Rubus fruiticosus*). Although Blackberry is a weed of National Significance (Department of the Environment 2016), thickets of this invasive plant species appeared to be useful for breeding by smaller-bodied birds. In fact, we found many nests of small-bodied birds in Blackberry thickets (Appendix 1). It is common for exotic plant species to provide some resources for wildlife in human-modified landscapes (Chambers and Dickman 2002; Lampert et al. 2014).

Conclusions

We detected an average of approximately three times more nests per site in remnants within farmlands than remnants surrounded by plantations. The proportion of generalist (non-woodland dependent) avian predator nests in remnants surrounded by pine plantations was significantly higher than that of remnants within farms. In addition, taxa with domed nests were more successful at nesting than species that constructed open cup/bowl nests in woodland remnants within farmlands. Different mechanisms may be driving nest success in woodland remnants with different surrounding matrices. Resource limitations (e.g. invertebrate prey) and the abundance of avian predators may be factors underpinning reduced overall abundance of nests and relatively low levels of nesting success in woodland remnants surrounded by stands of plantation pine.

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Table 1. Total number of nests and number of species that were detected and analysed for breeding success and number of nests of avian predators.

	Total number of nests detected	**Number of nests analysed for breeding success**	**Number of nests of generalist avian predators**
Remnants within farmlands	131 (32spp)	114 (29spp)	8 (2spp)
Remnants within plantations	44 (21spp)	44 (21spp)	15 (6spp)
Total	175 (42spp)	158 (39spp)	23 (6spp)

Figure 1. Sites where studies of bird breeding success were conducted. The squares show the location of remnant sites on farmlands and the circles indicate remnant sites within pine plantations.

Figure 2. Predicted breeding success rates (y-axis) plotted against body mass with approximate 95% confidence intervals.

Figure 1

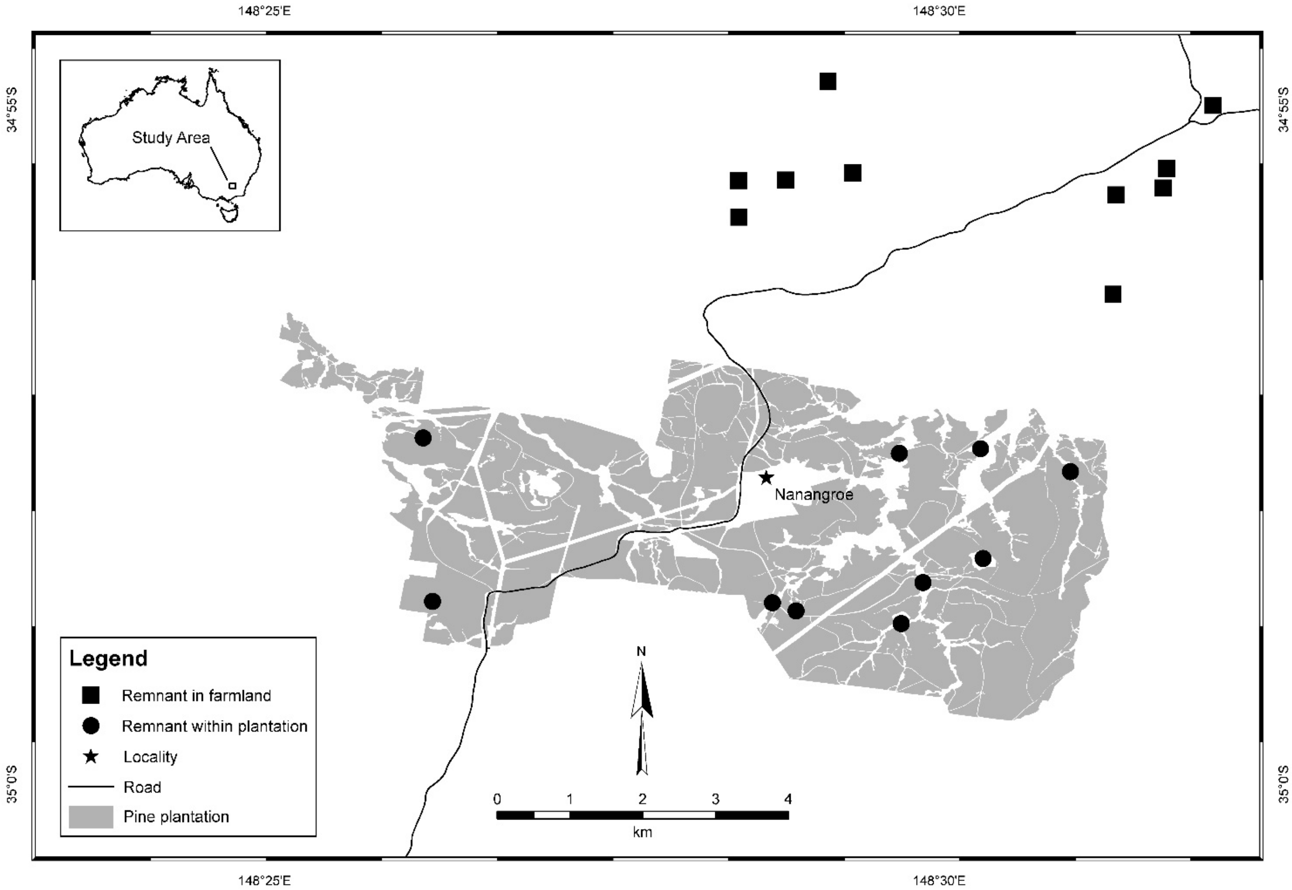
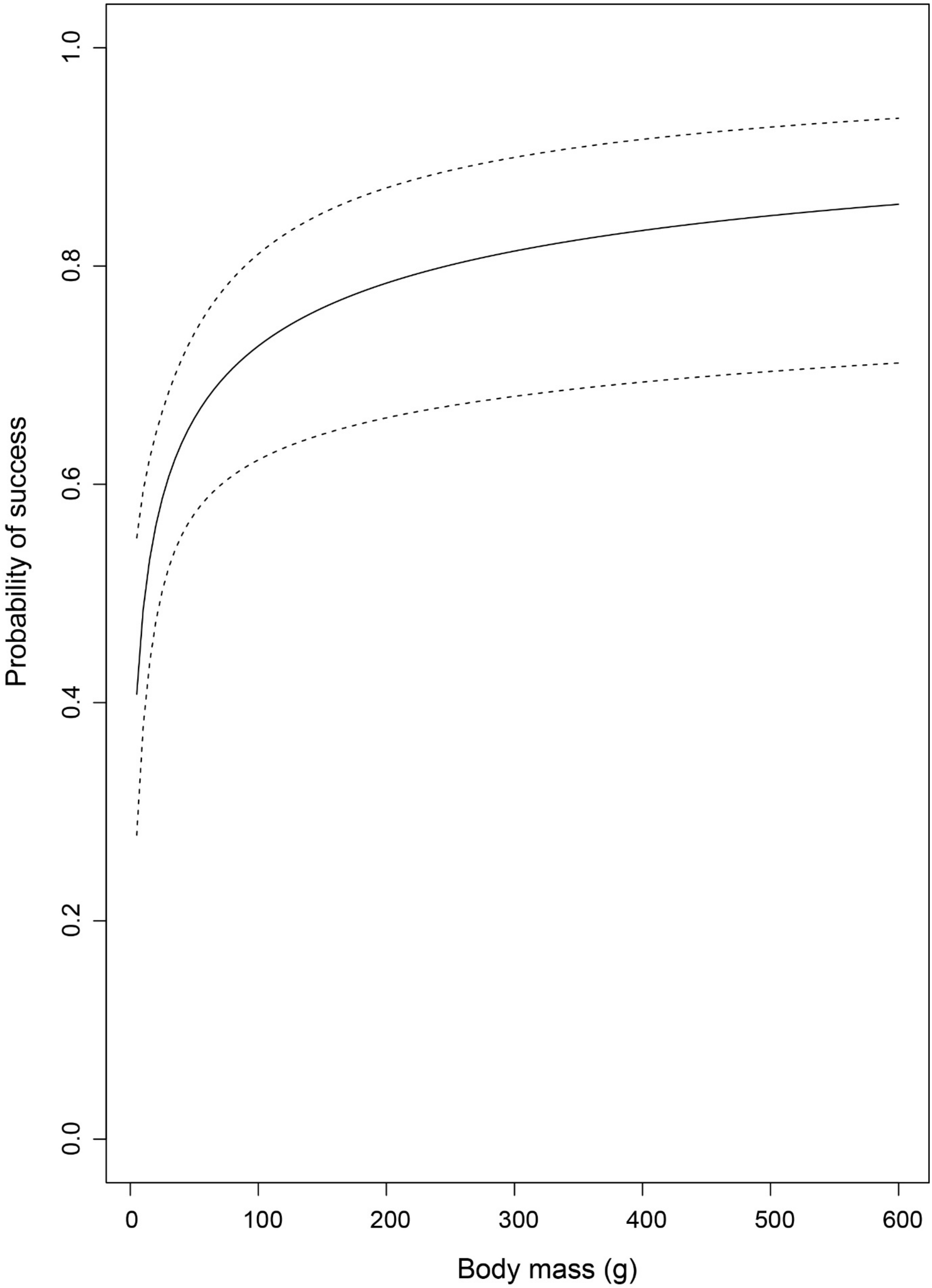

148°25'E
148°30'E
34°55'S
35°0'S
Study Area
Nanangroe
Legend
Remnant in farmland
Remnant within plantation
Locality
Road
Pine plantation
N
0
1
2
3
4
km

Figure 2



Probability of success
0.0
0.2
0.4
0.6
0.8
1.0
0
100
200
300
400
500
600
Body mass (g)

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Appendices

Appendix 1. Species of nests that we found with average body mass and nest type.

* indicates raptors and generalist avian predators. # shows woodland dependant avian predators.

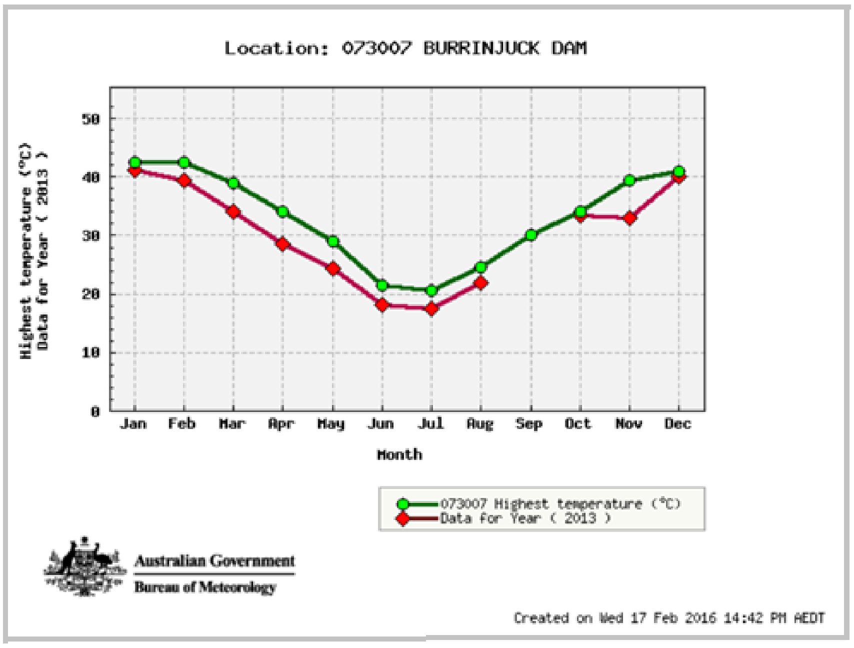
Common Name	Scientific Name	Number of Nests in Remnants surrounded by Farmland	Number of Nests in Remnants surrounded by Pine Plantations	Avg Body Mass (g)	Nest Type
Australasian Grebe	Tachybaptus novaehollandiae	3	0	219	Waterweed Platf
Australian Magpie*	Cracticus tibicen	6	6	296	Stick Platform
Australian Raven*	Corvus coronoides	0	4	638	Stick Platform
Black-faced Cuckoo-shrike	Coracina novaehollandiae	2	0	118	Cup/Bowl
Brown Thornbill	Acanthiza pusilla	0	2	7	Dome
Brown Treecreeper	Climacteris picumnus	2	0	32	Hollow/Burrow
Buff-rumped Thornbill	Acanthiza reguloides	4	3	8	Dome
Collared Sparrowhawk*	Accipiter cirrocephalus	0	1	172	Stick Platform
Crimson Rosella	Platycercus elegans	0	2	133	Hollow/Burrow
Dusky Woodswallow	Artamus cyanopterus	2	0	35	Cup/Bowl
Flame Robin	Petroica phoenicea	0	2	13	Cup/Bowl
Grey Butcherbird*	Cracticus torquatus	0	1	88	Stick Platform
Grey Fantail	Rhipidura albiscapa	4	1	8	Cup/Bowl
Jacky Winter	Microeca fascinans	2	0	16	Cup/Bowl
Laughing Kookabura*	Dacelo novaeguineae	0	1	339	Hollow/Burrow
Leaden Flycatcher	Myiagra rubecula	5	0	14	Cup/Bowl

Magpie-lark	Grallina cyanoleuca	4	0	87	Cup/Bowl
Mistletoebird	Dicaeum hirundinaceum	3	0	9	Dome
Noisy Fraiarbird#	Philemon corniculatus	27	1	101	Cup/Bowl
Pied Currawong*	Strepera graculina	2	2	332	Stick Platform
Rainbow Bee-eater	Merops ornatus	1	0	27	Hollow/Burrow
Red Wattlebird	Anthochaera carunculata	1	2	114	Cup/Bowl
Restless Flycatcher	Myiagra inquieta	2	0	21	Cup/Bowl
Rufous Songlark	Cincloramphus mathewsi	2	0	29	Cup/Bowl
Rufous Whistler	Pachycephala rufiventris	1	0	25	Cup/Bowl
Sacred Kingfisher	Todiramphus sanctus	0	1	43	Hollow/Burrow
Silvereye	Zosterops lateralis	2	0	12	Cup/Bowl
Spotted Pardalote	Pardalotus punctatus	1	0	9	Hollow/Burrow
Striated Pardalote	Pardalotus striatus	2	2	12	Hollow/Burrow
Superb Fairy-wren	Malurus cyaneus	5	4	10	Dome
Weebill	Smicrornis brevirostris	0	1	6	Dome
Western Gerygone	Gerygone fusca	1	0	7	Dome
White-browed Scrubwren	Sericornis frontalis	0	1	13	Dome
White-browed Woodswallow	Artamus superciliosus	12	0	36	Cup/Bowl
White-faced Heron	Egretta novaehollandiae	2	0	585	Stick Platform
White-throated Gerygone	Gerygone olivacea	6	5	7	Dome
White-throated treecreeper	Cormobates leucophaea	2	1	23	Hollow/Burrow
White-winged Chough#	Corcorax melanorhamphos	2	0	368	Cup/Bowl
White-winged Triller	Lalage sueurii	5	0	25	Cup/Bowl
Willie Wagtail	Rhipidura leucophrys	11	0	21	Cup/Bowl
Yellow-faced Honeyeater	Caligavis chrysops	1	0	17	Cup/Bowl
Yellow-rumped Thornbill	Acanthiza chrysorrhoa	6	1	10	Dome

Appendix 2. Species showing evidence of nesting in pine trees

Common Name	**Scientific Name**	**Abundance**	**Breeding stage/Behaviours**
Brown Thornbill	Acanthiza pusilla	1	Fledglings
Brown Thornbill	Acanthiza pusilla	2	Carrying food into pine stands
Buff-rumped Thornbill	Acanthiza reguloides	1	Carrying food into pine stands
Buff-rumped Thornbill	Acanthiza reguloides	1	Carrying nesting materials into pine stands
Eastern Yellow Robin	Eopsaltria australis	1	Incubating on nest in pine tree
Grey Fantail	Rhipidura albiscapa	1	Fledglings
Grey Fantail	Rhipidura albiscapa	1	Incubating on nest in pine tree
Grey Fantail	Rhipidura albiscapa	3	Carrying nesting materials into pine stands
Silvereye	Zosterops lateralis	1	Carrying nesting materials into pine stands
White-browed Scrubwren	Sericornis frontalis	1	Feeding nestlings
White-browed Scrubwren	Sericornis frontalis	1	Nestlings
Yellow-faced Honeyeater	Caligavis chrysops	1	Feeding fledgelings
Yellow-faced Honeyeater	Caligavis chrysops	1	Carrying nesting materials into pine stands
Yellow-rumped Thornbill	Acanthiza chrysorrhoa	1	Fledglings

Appendix 3. Figure derived from Bureau of Meteorology website, showing the highest temperature of a month in 2013 at Burrinjuck Dam weather station, compared with historical highest temperature of a month from 1965 to 2016.



Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Highest temperature (°C) for years 1965 to 2016	42.5	42.4	39.0	34.0	29.0	21.5	20.6	24.5	30.0	34.0	39.4	40.9	42.5	50
Statistics	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**	**Years**
Highest temperature (°C) for year 2013	41.1	39.4	34.0	28.5	24.3	18.1	17.5	22.0		33.5	33.0	40.0		1